International Network on Remote Sensing of Terrestrial and Aquatic Fluorescence, 5 – 8 March 2019, Davos, Switzerland

Validation of Sentinel-2 cloud masking and classification products – potential for Sentinel-3 validation?

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SENTINEL 2

esa

European Commission

TELESPAZIO a LEONARDO and THALES company

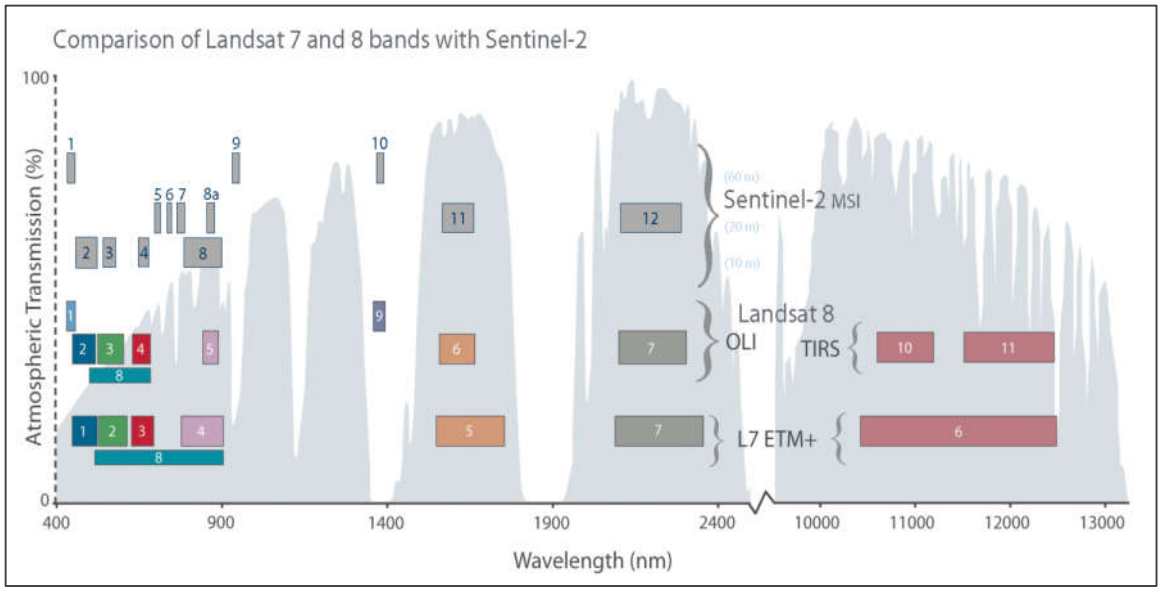
DLR

TELESPAZIO VEGA

Sentinel-2 Mission

- optical mission for land and coastal region monitoring and emergency services
- Constellation of 2 satellites S2A and S2B
- Polar, sun-synchronous orbit at altitude: 786.13km with LTDN 10h30 AM
- Global coverage and revisit period of <= 5 days

	Sentinel-3 OLCI	Sentinel-2 MSI
Spectral range (nm)	400 to 1020	442 to 2202
Spectral bands	21	13
Band width (nm)	2.5 to 40	18 to 242
Spatial resolution (m)	300	10, 20, 60
Swath width (km)	1270	290



S-2 band	Center (nm)`	Spectral Width Δ (nm)	Spatial Re-solution (m)	Purpose in L2A processing context
B1	443	20	60	Atmospheric Correction
B2	490	65	10	Sensitive to Vegetation Aerosol Scattering
B3	560	35	10	Green peak, sensitive to total chlorophyll in vegetation
B4	665	30	10	Max Chlorophyll absorption
B8	842	115	10	Leaf Area Index (LAI)
B8a	865	20	20	Used for water vapour absorption reference
B9	945	20	60	Water Vapour absorption atmospheric correction
B10	1375	30	60	Detection of thin cirrus for atmospheric correction
B11	1610	90	20	Soils detection
B12	2190	180	20	AOT determination

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Sen2Cor Processor and Products

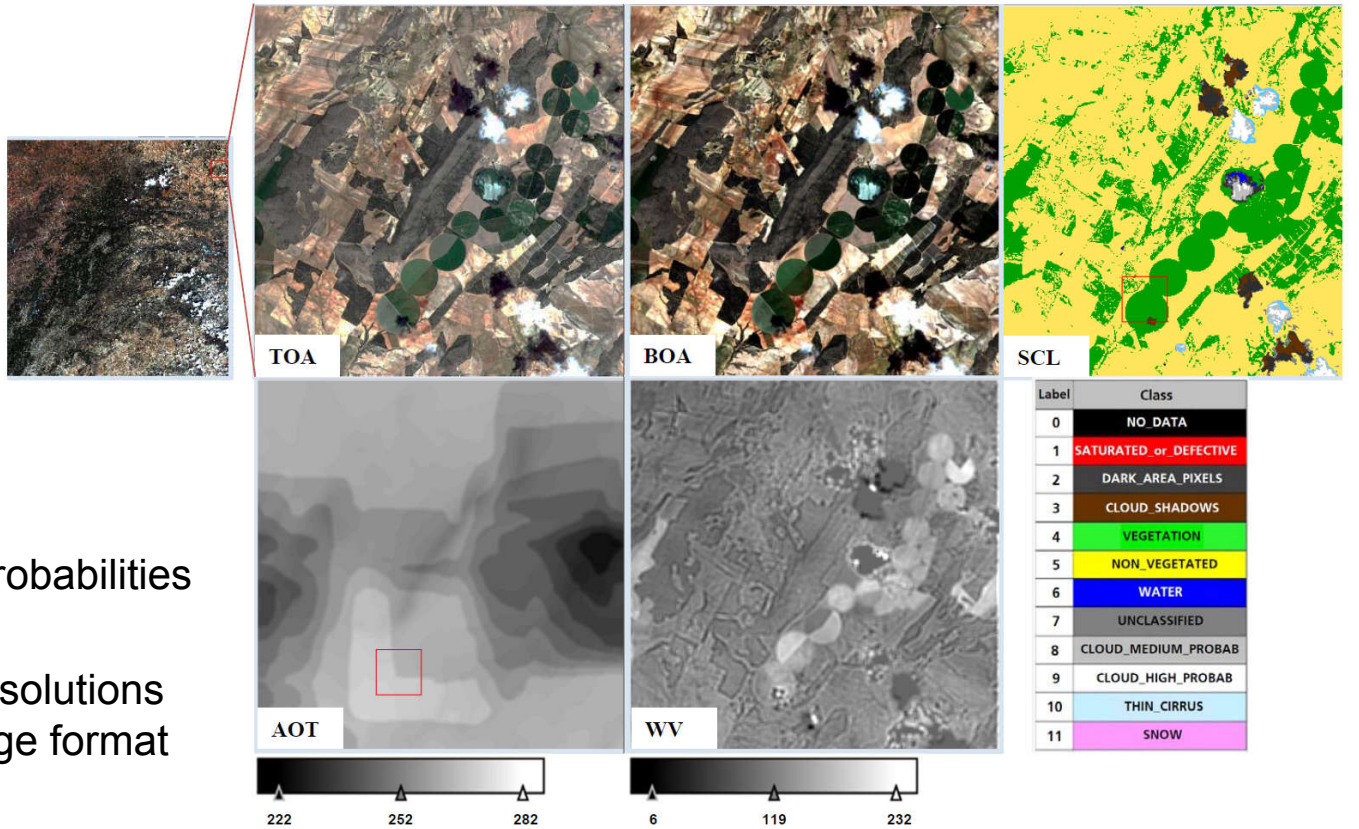
- Atmospheric correction processor, developed by Telespazio VEGA Deutschland GmbH on behalf of ESA

- Corrects single-date Sentinel-2 L1C Top-Of-Atmosphere (TOA) products from the effects of the atmosphere and delivers L2A Bottom-Of-Atmosphere (BOA) surface reflectance product

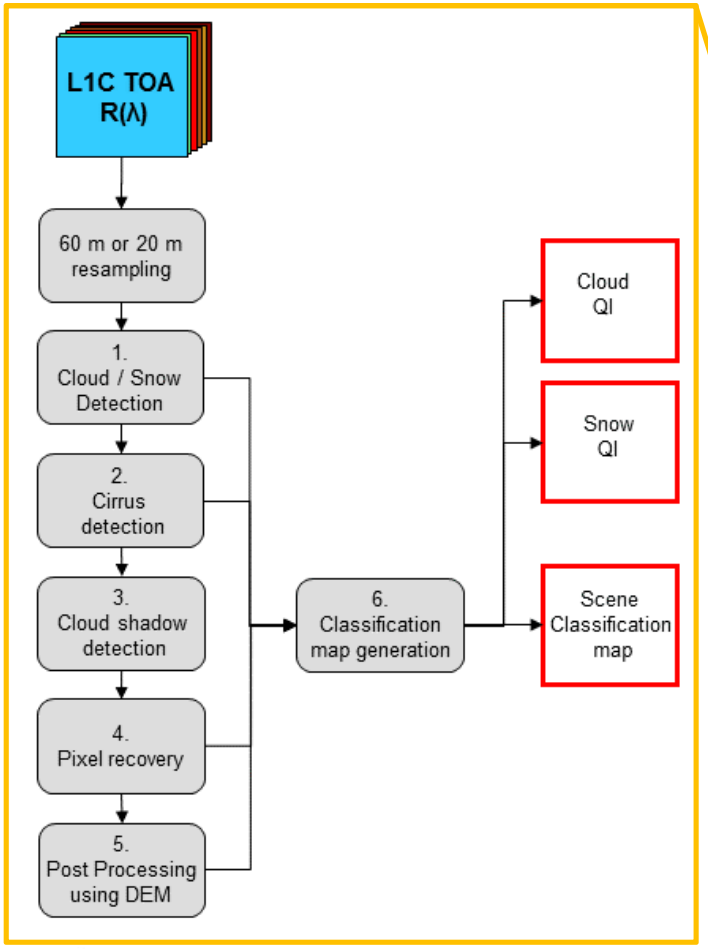
- Additional outputs:
  Aerosol Optical Thickness (AOT) map,
  Water Vapour (WV) map,
  Scene Classification (SCL) map,
  Quality Indicators for cloud and snow probabilities

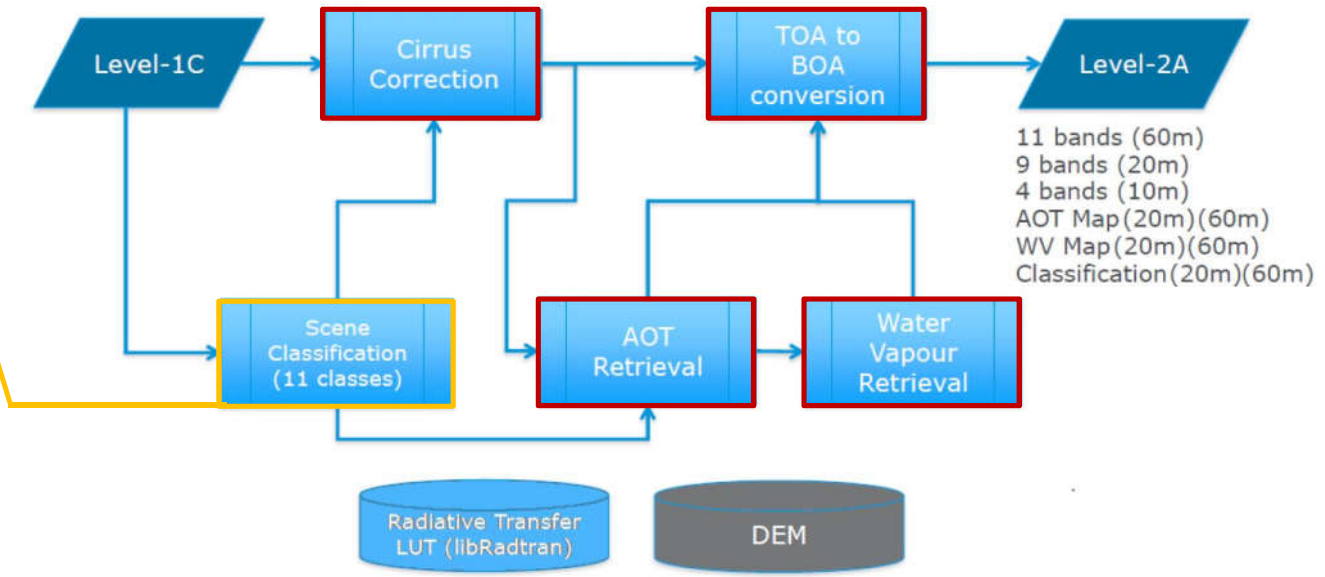
- Sen2Cor outputs provided for spatial resolutions 60m, 20m and 10m, in JPEG 2000 image format

Barrax (Spain) acquired on 19.05.2017, S2A_MSIL2A_20170519T105651_N0205_R094_20170529T104446



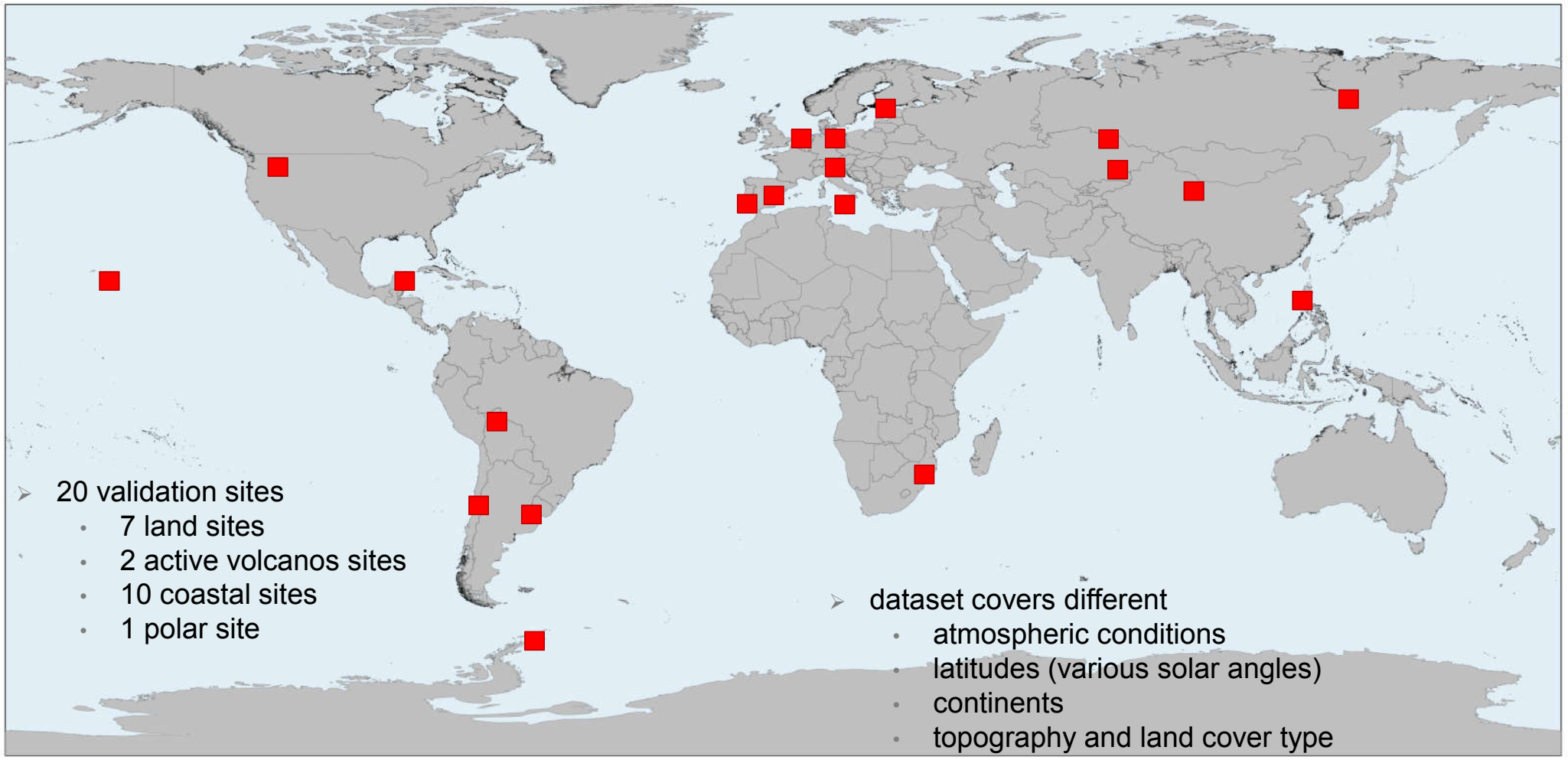
Sen2Cor Processor Framework - Scene Classification Module (SCL)





- Two main modules : Scene Classification (SCL), Atmospheric Correction (AC)
- DEM downloaded automatically by the processor (SRTM) or provided by the user in DTED format
- SCL is mainly based on a series of threshold tests on L1C spectral bands, band ratios and indices
- ESA CCI auxiliary data support for water and snow detection

Validation Dataset



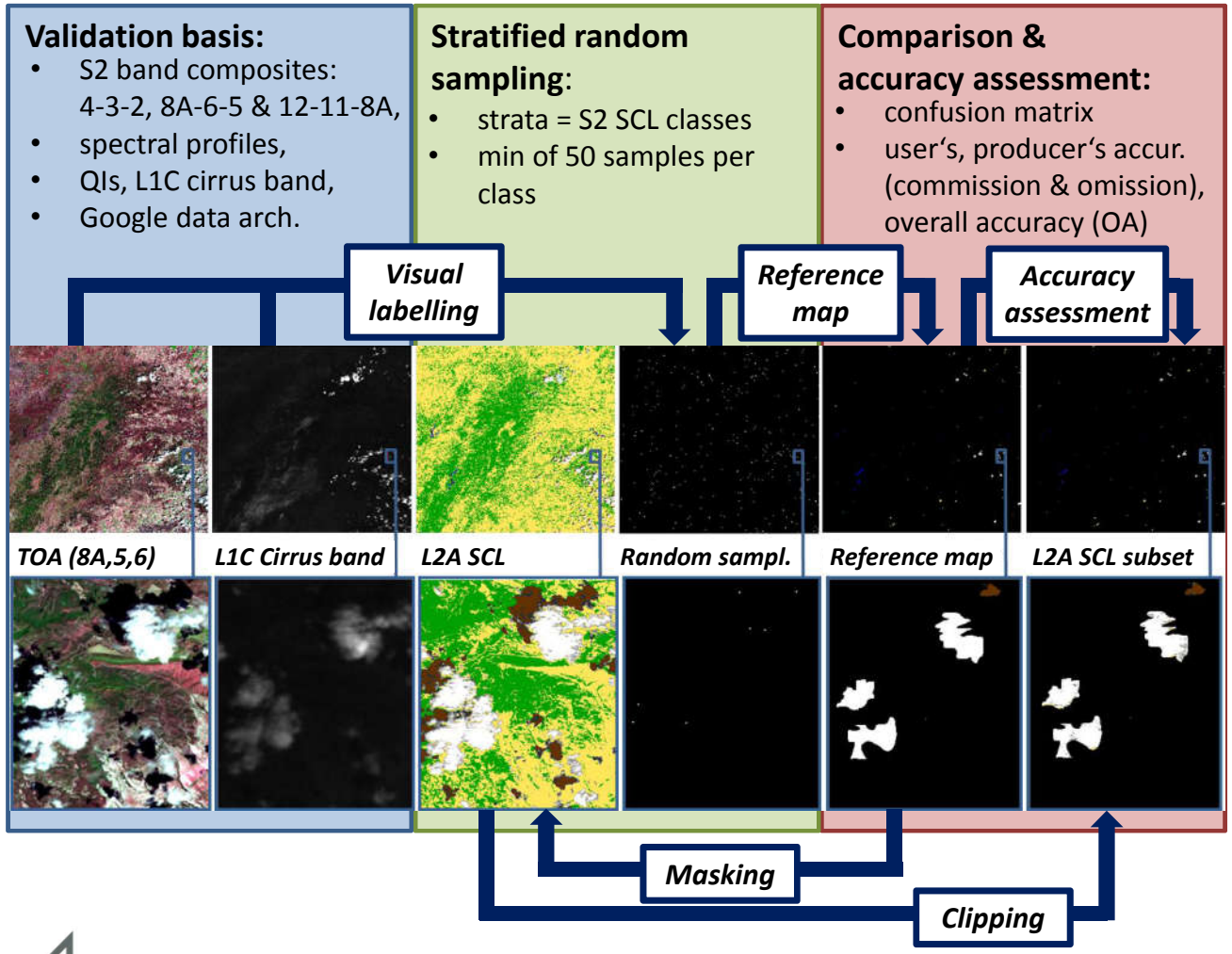
- 20 validation sites
  - 7 land sites
  - 2 active volcanos sites
  - 10 coastal sites
  - 1 polar site

- dataset covers different
  - atmospheric conditions
  - latitudes (various solar angles)
  - continents
  - topography and land cover type

Validation Dataset

Country	Site	Tile	Date	L1C clouds (%)	Land cover	Special features
Antarctic	Antarctic	21EVK	04.02.2016	9,91	snow, ice, water	clouds over snow, clouds and shadows over water
Argentina	Casleo	19HDE	12.08.2016	21,73	snow, rural, mountains	transparent clouds, cloud shadows, topographic shadows
Argentina	Buenos Aires	21HUC	27.08.2018	0,00	urban, rural, water	sediment in water, very bright objects
Bolivia	Puerto Siles	19LHF	06.09.2018	0,00	rural, vegetation, water	different water color and sediment, bright soil
China	Dunhuang	46TFK	22.01.2018	24,14	snow, rural, desert	no clouds, solar panels,
Estonia	Tallin	35VLG	14.07.2018	2,09	urban, rural, water	algal bloom, bright objects
Germany	Berlin	33UUU	04.05.2018	0,87	urban, rural, water	asparagus fields
Italy	Etna Volcano	33SVB	09.03.2017	6,86	snow, rural, urban, water	active volcano, burning and burned area, ash cloud
Italy	Venice	32TQR	16.09.2018	2,42	coast, industry, urban, rural, water	black coastline, topographic shadows, bright object
Kazakhstan	Pavlodar	43UET	26.07.2018	0,13	rural, industrial and natural water	different water colours,
Kazakhstan	Balkhash	43TFM	30.07.2018	7,18	water, rural	black coastal line
Mexico	Cancun	16QDJ	27.05.2018	6,68	rural, vegetation, water	waves, sediment, algas(?), clouds
Mosambique	Maputo	36JVS	13.07.2018	0,00	rural, urban, water	burned area, sediment in water,
Netherlands	Amsterdam	31UFU	13.09.2018	4,73	rural, urban, vegetation, water	black coastline, clouds and cloud shadows over water
Phillipines	Manila	51PTS	19.03.2018	1,44	urban, rural, water	sediment / aquacultures, very bright objects,
Portugal	Lagos	29SNB	08.08.2018	0,00	rural, water	waves, sediment, burned area, bright objects
Russia	Yakutsk	52VEP	08.03.2016	61,53	snow, rural	transparent clouds
Spain	Barrax	30SWH	09.05.2017	17,67	rural, vegetation, mountains	cumulus and cirrus clouds
Spain	Barrax	30SWH	19.05.2017	1,64	rural, vegetation, mountains	cumulus clouds
USA	Rimrock	11TMM	12.05.2018	0,74	snow, rural, urban, water	very bright objects
USA-Hawaii	Kilauea Volcano	05QKB	23.04.2018	28,41	rural, water	active volcano, burning and burned area, ash cloud

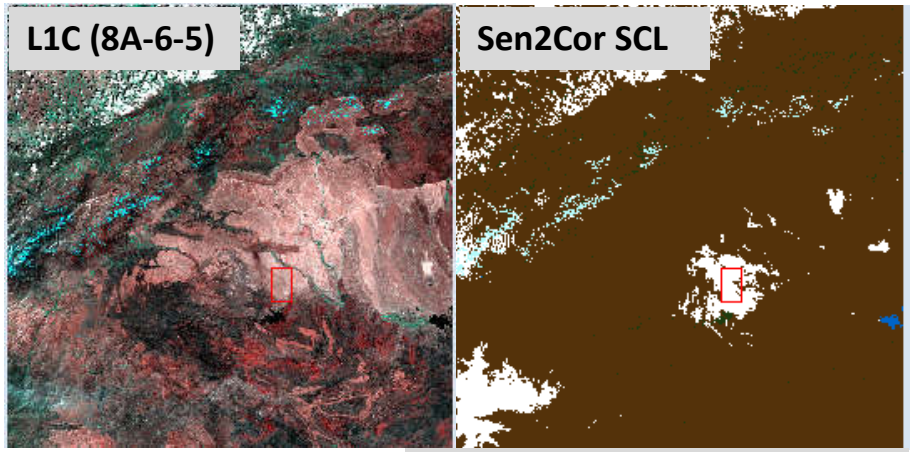
Validation Procedure



- Statistical metrics:
  - Overall accuracy (OA)
    Percentage of correctly classified pixels.
  - Omission error (OE) / Producer Accuracy (PA)
    The share of reference pixels in that class that have been "omitted" in the classification image.
    OE [%] = 100 - Producer Accuracy
  - Commission error (CE) / User Accuracy (UA)
    Percentage of class pixels in the classification image which are falsely classified.
    CE [%] = 100 - User Accuracy
- Statistics are calculated for:
  - All classes (original SCL product)
  - Clear pixels (over land and water) separation
  - Clouds (medium + high probability clouds + cirrus) separation

Validation Procedure – Limitations

- Stratified random sampling is based on classification SCL (class = strata)
  - it can bias validation results, where Sen2Cor classification failed



Quarzazate (Morocco) 17.04.2016

- Reference samples set is inbalanced, semi-proportional to the class area
- Definition of thin cirrus and visual interpretation of clouds is subjective & challenging
- Internal test on the subjectivity of the validation method (4 validating persons, 2 products) revealed quite stable results (st.dev of classification accuracy ~5-6%). More extended tests are required.
- In preparation classification validation protocol for L2A to assure validation quality and comparability between algorithms

Validation of SCL Products – per site

Country	Site	Tile	Date	L1C clouds	OA	OA clear pixels	OA clouds	Pixel validated
Antarctic	**Antarctic**	21EVK	04.02.2016	9,91	94,7	96,8	98,8	527803
Argentina	**Casleo**	19HDE	12.08.2016	21,73	63,8	86,1	98,1	186238
Argentina	**Buenos Aires**	21HUC	27.08.2018	0,00	91,8	97,3	no clouds	31841
Bolivia	**Puerto Siles**	19LHF	06.09.2018	0,00	91,1	94,9	94,8	80580
China	**Dunhuang**	46TFK	22.01.2018	24,14	57,3	66,2	no clouds	105454
Estonia	**Tallin**	35VLG	14.07.2018	2,09	84,3	90,4	95,6	71773
Germany	**Berlin**	33UUU	04.05.2018	0,87	93,4	96,5	no clouds	51964
Italy	**Etna Volcano**	33SVB	09.03.2017	6,86	95,8	97,9	99,4	132340
Italy	**Venice**	32TQR	16.09.2018	2,42	80,3	91,0	89,0	103780
Kazakhstan	**Pavlodar**	43UET	26.07.2018	0,13	70,1	82,6	83,2	90803
Kazakhstan	**Balkhash**	43TFM	30.07.2018	7,18	77,4	93,7	95,7	94578
Mexico	**Cancun**	16QDJ	27.05.2018	6,68	90,5	93,8	95,2	32082
Mosambique	**Maputo**	36JVS	13.07.2018	0,00	80,5	85,1	82,5	90043
Netherlands	**Amsterdam**	31UFU	13.09.2018	4,73	71,1	81,5	88,7	100018
Phillipines	**Manila**	51PTS	19.03.2018	1,44	82,1	90,0	91,6	106263
Portugal	**Lagos**	29SNB	08.08.2018	0,00	96,8	97,3	no clouds	69753
Russia	**Yakutsk**	52VEP	08.03.2016	61,53	69,9	93,8	92,9	177983
Spain	**Barrax**	30SWH	09.05.2017	17,67	64,6	96,9	98,7	141546
Spain	**Barrax**	30SWH	19.05.2017	1,64	90,5	98,7	99,5	104799
USA	**Rimrock**	11TMM	12.05.2018	0,74	90,2	98,2	99,2	103394
USA-Hawaii	**Kilauea Volcano**	05QKB	23.04.2018	28,41	60,4	75,4	74,2	118357
				Average OA:	**80,9**	**Averaged reference per SCL:**		**120066**
						Total validated pixels:		**2521392**

Best case:
OA > 90%;
OA clear pixels > 94%
OA clouds > 95%

Moderate case:
OA 70-85%;
OA clear pixels 80-94%
OA clouds 80-96%

Poor case:
OA >= 64 %
but
OA clear pixels > 86%
OA clouds > 93%

The worst case:
OA <= 60%;
OA clear pixels &
OA clouds < 75%

Validation of SCL Products – valid pixels, clouds

Clear (valid) pixels over land and water				
	Clear pixels Land-Water	**Others**	**Sum**	**Commission error (CE)**
Clear pixels Land-Water	1119112	137273	1256385	**10,9**
Others	83033	1181974	1265007	6,6
Sum	1202145	1319247	2521392	
Omission error (OE)	**6,9**	10,4		
All clouds				
	Clouds	**Others**	**Sum**	**Commission error**
Clouds	577133	34464	611597	**5,6**
Others	114256	1795539	1909795	6,0
Sum	691389	1830003	2521392	
Omission error	**16,5**	1,9		

(+) Good performance for clear pixels detection (CE=10,9%; OE=6,9%)

(–) High omission error for clouds detection (CE=5,6%; OE=16,5%)

Class	Commission error	Omission error
Cloud shadows	4,5	55,6
Vegetation	17,7	0,5
Non vegetated	16,1	16,7
Water	5,6	1,9
Snow	5,5	10,3

(+) Very low omission for vegetation and water

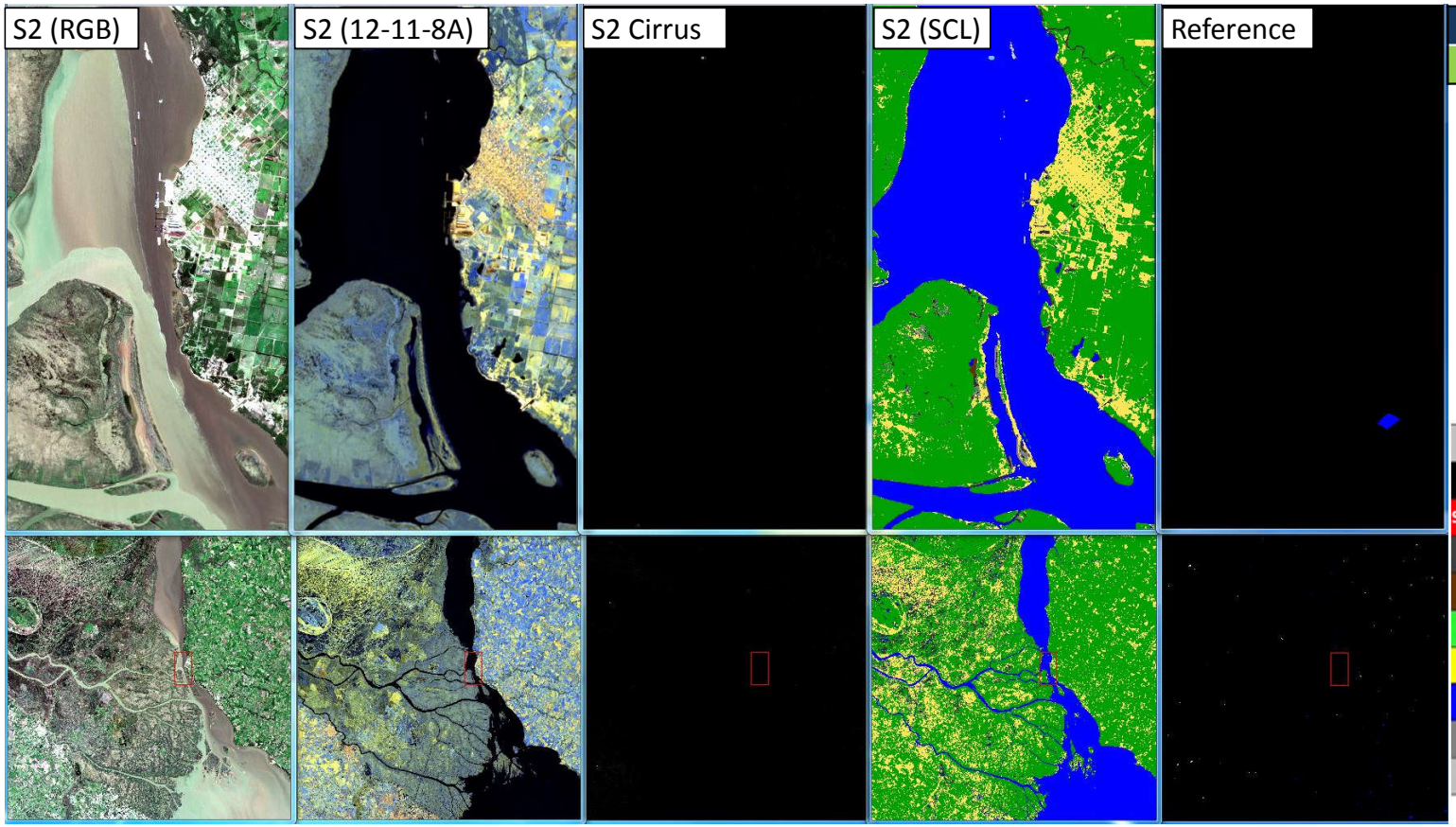
(+) Very low commission for cloud shadows, water and snow/ice

(–) Very high omission for cloud shadows

(–) Higher commission for vegetation and non-vegetated pixels

Validation of SCL Products – Example 1: Buenos Aires

with regard to Sentinel-3 Mission objective: **Measuring ocean and land-surface colour.**



OA	OA clear	OA clouds
91,8	97,3	no clouds

(+) Different water colors and ship traffic possible to identify (but it is not the focus of SCL classification)

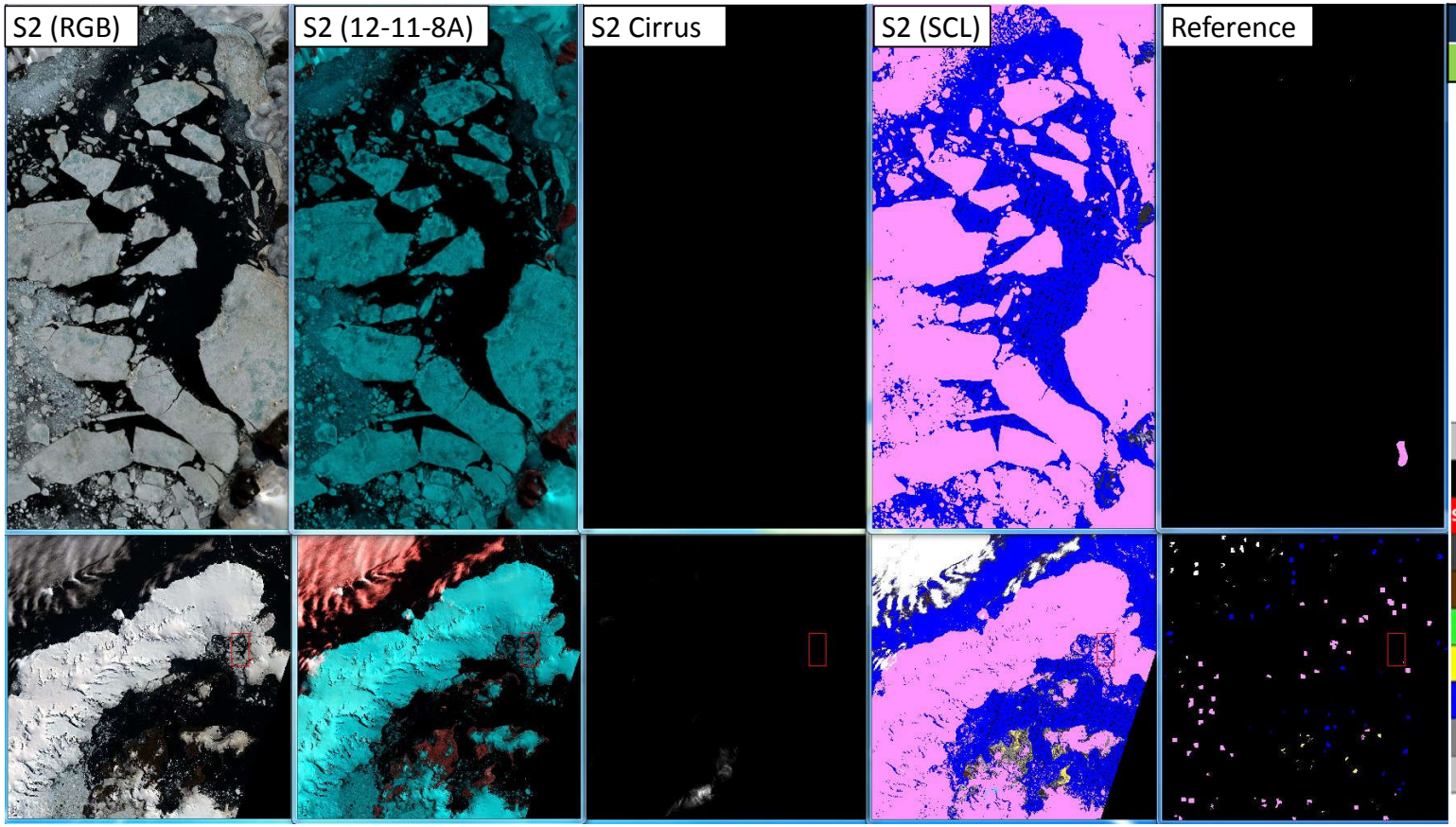
(+) Water, vegetation and non vegetated recognized correctly

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

S2A_MSIL2A_20180827T135111_N0206_R024_T21HUC_20180827T201500.SAFE

Validation of SCL Products – Example 2: Antarctic

with regard to Sentinel-3 Mission objective: **Monitoring sea and land ice topography.**



OA	OA clear	OA clouds
94,7	96,8	98,8

(+) Clouds over water and snow classified properly

(+) Water, snow and ice classified correctly

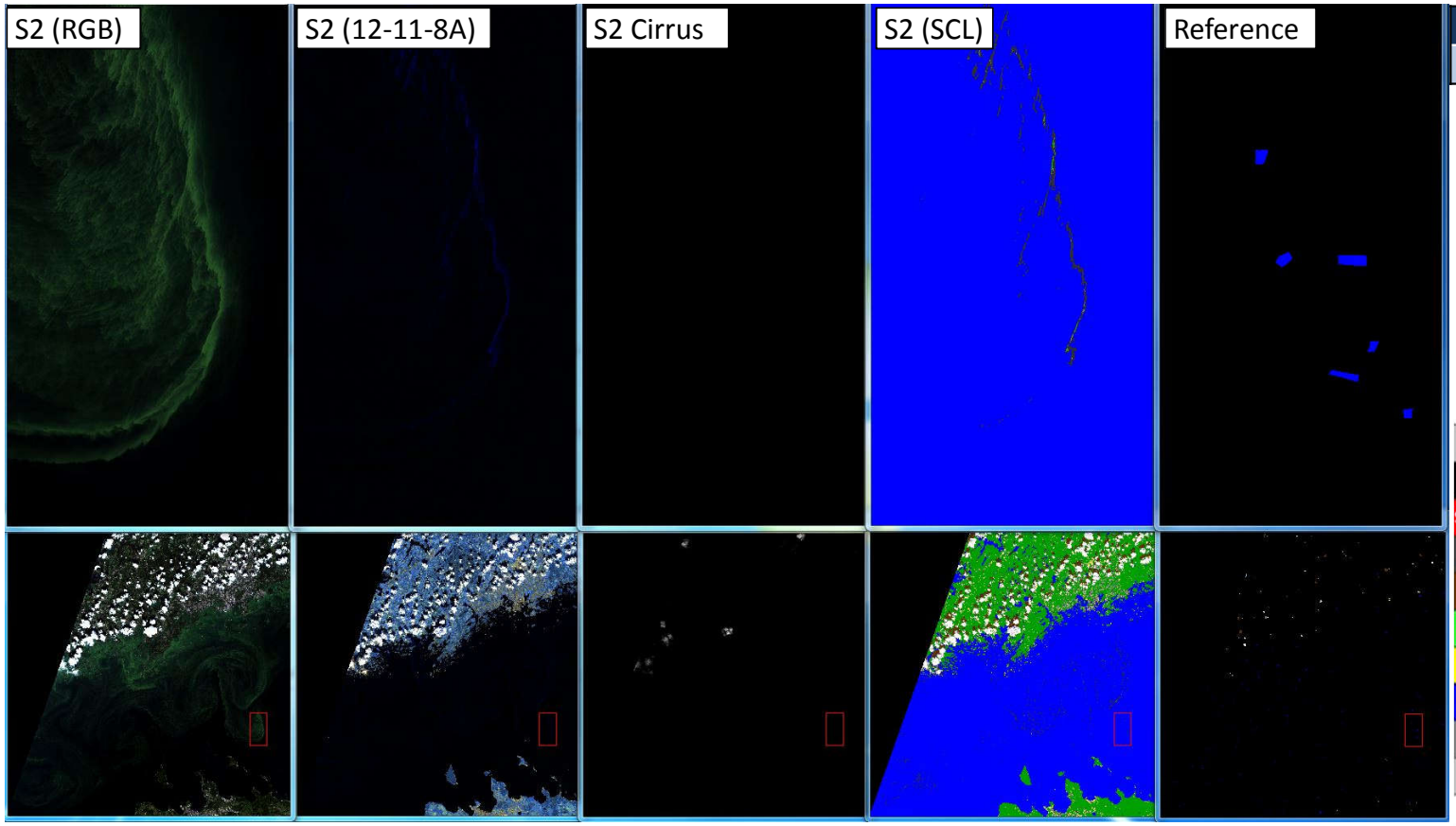
(–) Omission of non vegetated towards clouds

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

S2A_USER_PRD_MSIL2A_PDMC_20160206T015135_R095_V20160204T131909_20160204T131909.SAFE

Validation of SCL Products – Example 3: Tallin

with regard to Sentinel-3 Mission objective: **Sea-water quality and pollution monitoring.**



S2B_MSIL2A_20180714T094029_N0206_R036_T35VLG_20180714T132842.SAFE

OA	OA clear	OA clouds
84,3	90,4	95,6

(+) Cloud, vegetation and water classified properly

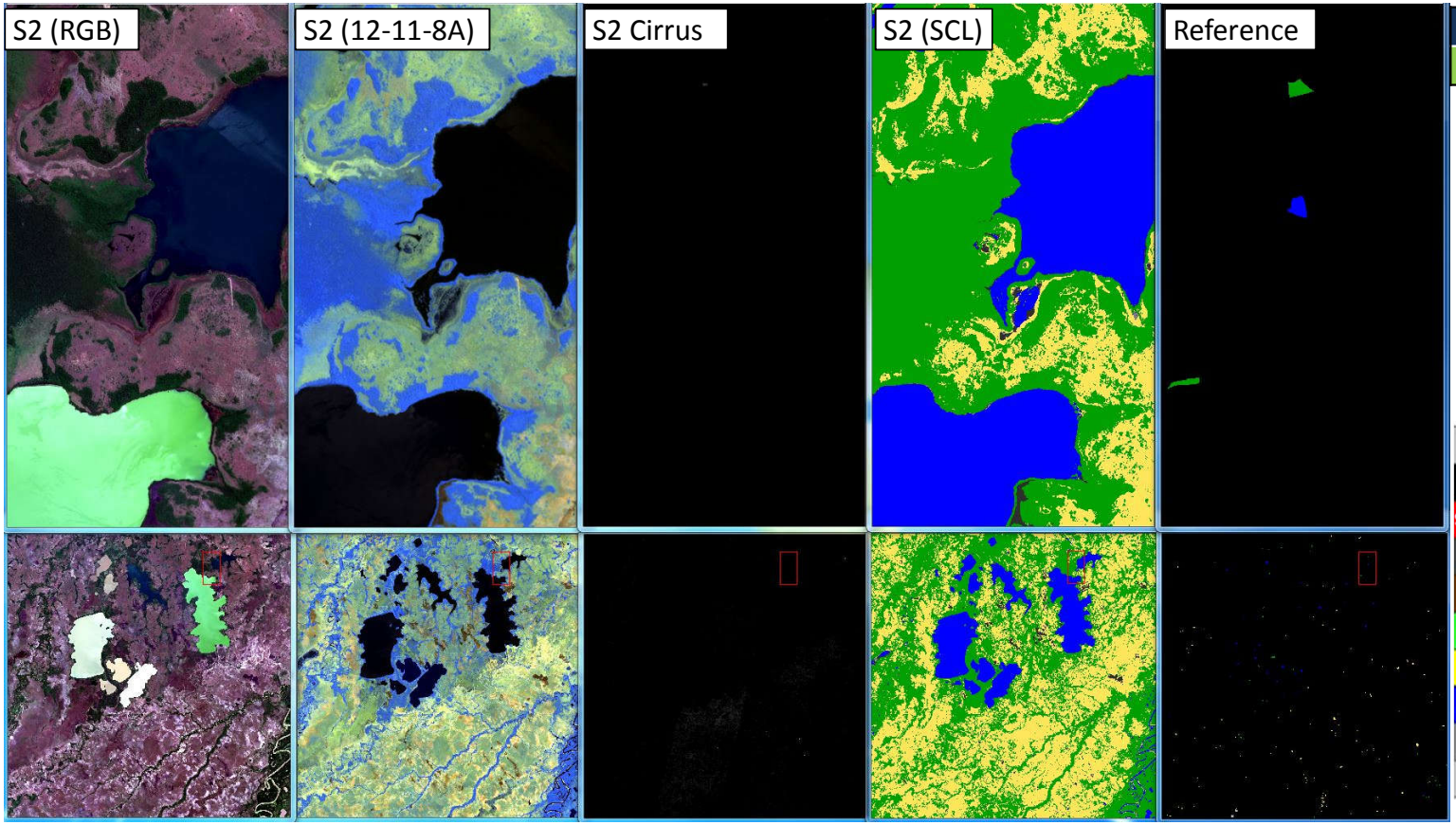
(+) Algal bloom possible to identify (but it is not the focus of SCL classification)

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

(–) Lower OA of clear pixels due to misclassification of bright harbor area as clouds

Validation of SCL Products – Example 4: Puerto Siles

with regard to Sentinel-3 Mission objective: **Inland water monitoring, including rivers and lakes.**



OA	OA clear	OA clouds
91,1	94,9	94,8

(+) Water classified properly despite of different water colors

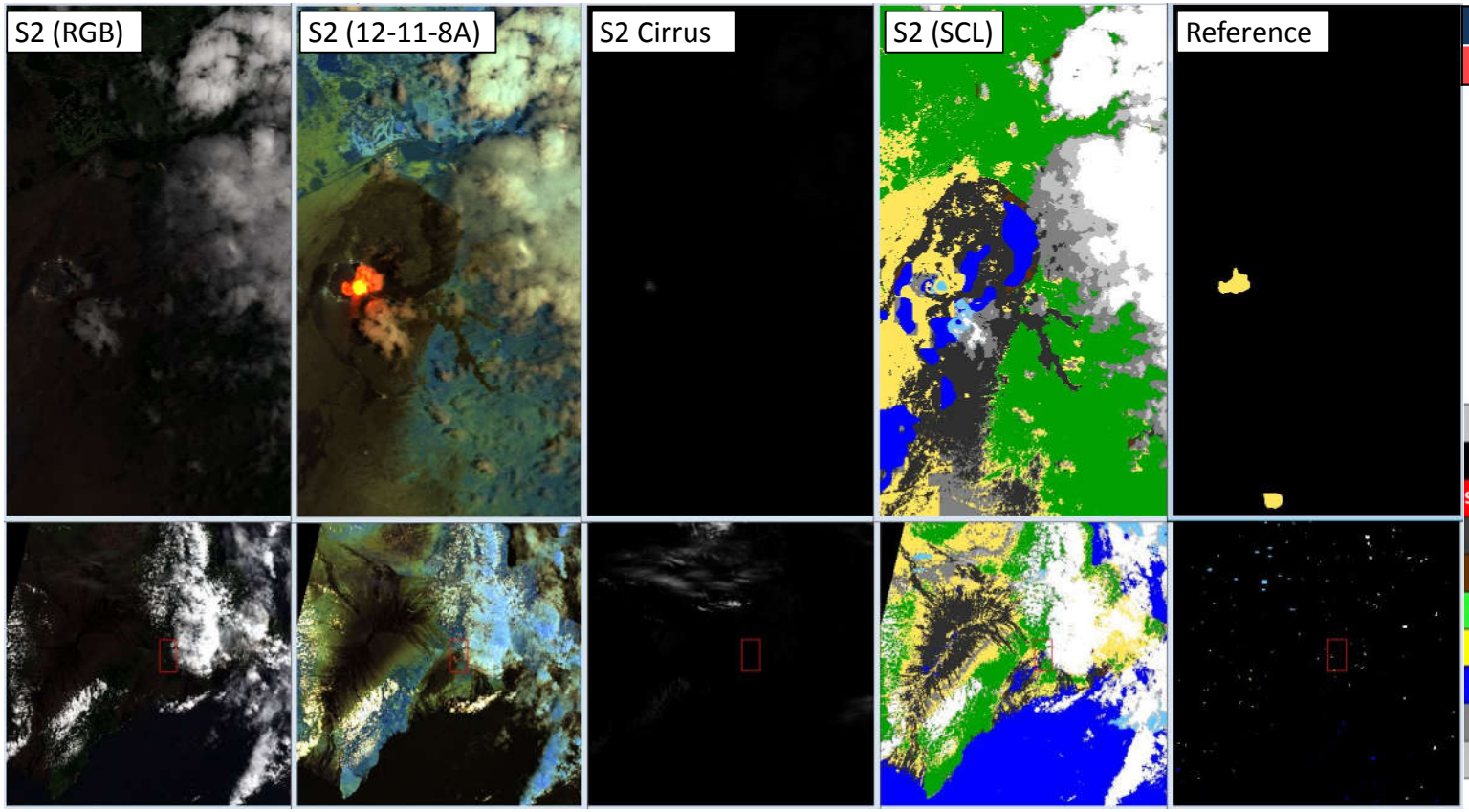
(+) Vegetation and non vegetated recognized correctly

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

S2B_MSIL2A_20180906T143739_N0206_R096_T19LHF_20180906T195021.SAFE

Validation of SCL Products – Example 5: Kilauea Volcano

with regard to Sentinel-3 Mission objective: **Land-use change monitoring. Forest cover mapping. Fire detection.**



OA	OA clear	OA clouds
60,4	75,4	74,2

(+) Cloud, vegetation & non vegetation classified properly

(+) Fire and burned area partially recognized; burned area classified as dark area

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

(–) Commission of water around volcano

(–) Unclear treatment of haze or smoke (no class defined)

S2B_MSIL2A_20180423T205939_N0206_R014_T05QKB_20180423T221316.SAFE

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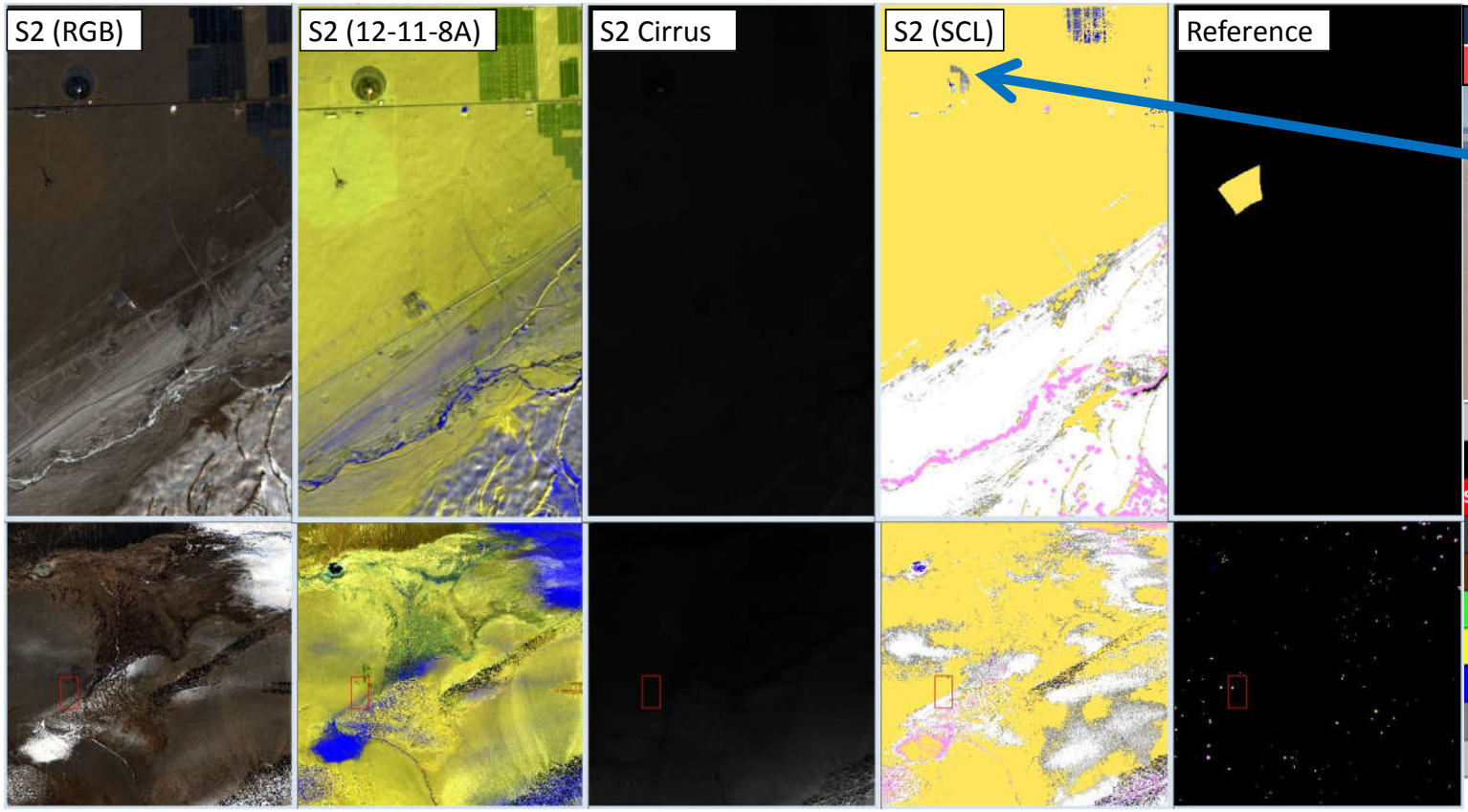
Validation of SCL Products – Limitations – Example 6: Dunhuang

(-) solar panels, snow, sandy roads and dunes misclassified as clouds



OA	OA clear	OA clouds
57,3	66,2	no clouds

Class
NO_DATA
SATURATED_or_DEFECTIVE
DARK_AREA_PIXELS
CLOUD_SHADOWS
VEGETATION
NON_VEGETATED
WATER
UNCLASSIFIED
CLOUD_MEDIUM_PROBAB
CLOUD_HIGH_PROBAB
THIN_CIRRUS
SNOW

(–) Snow classified as cloud

(+) Non vegetated recognized correctly

S2B_MSIL2A_20180122T043059_N0206_R133_T46TFK_20180122T062244.SAFE

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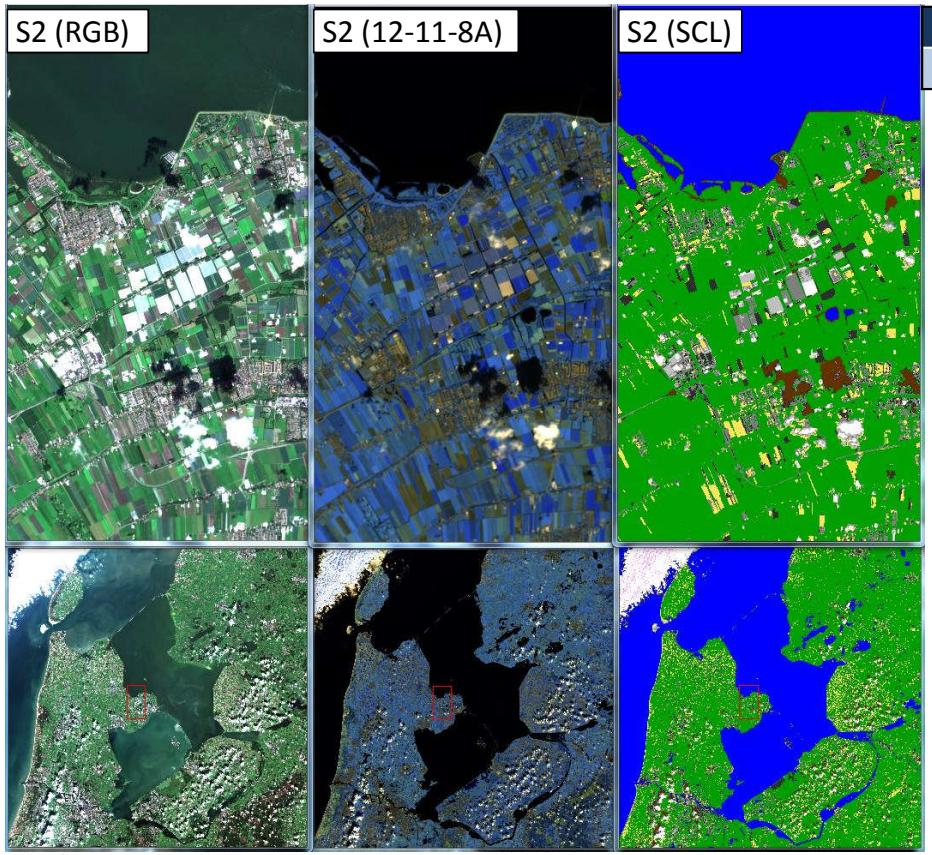
Validation of SCL Products – Limitations – Example 7: Amsterdam & more

(-) High misclassification rate for bright objects e.g. urban areas, highly reflecting roofs, asparagus fields covered by foil – classified as clouds



OA	OA clear	OA clouds
71,1	81,5	88,7

(-) High omission and commision errors of medium cloud probability and cirrus classes
- – Confusion between cloud classes definitions and some overlapping problems

(-) High omission and commision errors for dark area pixels
- – Confusion between cloud shadows, topographic shadows and dark area pixel
- – Confusion in the definition of dark area pixel (topographic shadow? also dark soil, burned area?)

S2B_MSIL2A_20180913T105019_N0208_R051_T31UFU_20180913T141638.SAFE

Summary

- Very good separation of coastal line and water, even if affected by special features like algae bloom or sediment

- Averaged overall performance of Sen2Cor 2.5 for 21 products reaches 80,9%
  - ➢ Very high accuracy for water, vegetation and snow / ice classes
  - ➢ Very low commission error for cloud shadows
  - ➢ High misclassification rate for bright objects (urban, arid) – improvement needed, work ongoing
  - ➢ Separation of topographic shadows from other dark features allocated in the dark area class is aimed
- Good performance for clear pixels (over land and water) and clouds (3 cloud classes) detection:
  - ➢ CE and OE of clear pixels separation CE=10,9% and OE=6,9% respectively
  - ➢ CE and OE of cloud separation CE=5,6% and OE=16,5% respectively
  - ➢ Consolidated cloud mask could provide high quality support for the users applications – work ongoing for forthcoming Sen2Cor processor evolutions

- Sen2Cor processor can be freely downloaded and used http://step.esa.int/main/third-party-plugins-2/sen2cor/
- L2A Product Performance now reported in the L2A Data Quality Report:

  https://sentinels.copernicus.eu/documents/247904/685211/Sentinel-2-L2A-Data-Quality-Report

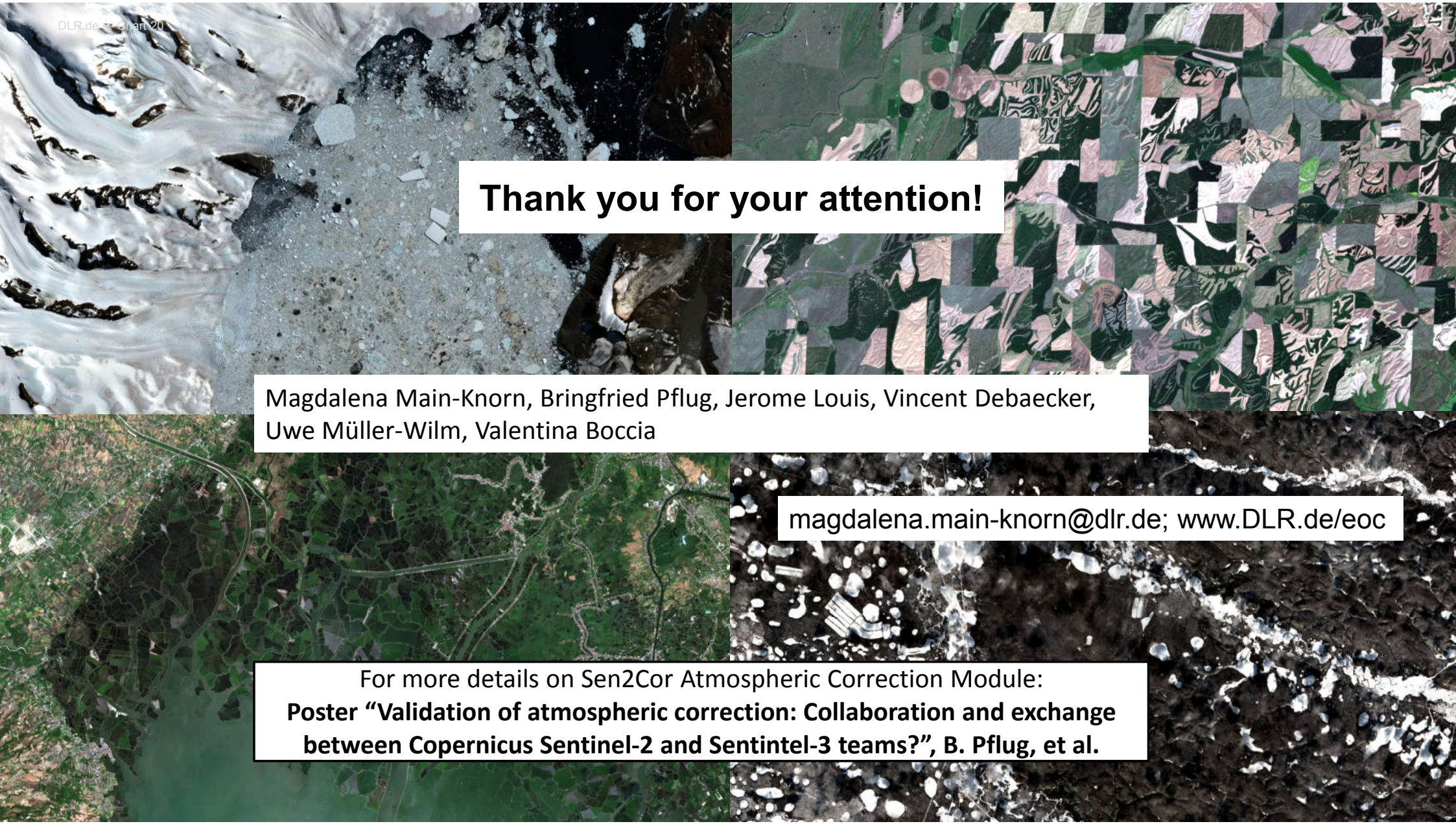
Potential for Sentinel-3 Validation

- Objectives of the Sentinel-3 OLCI Mission and the Sentinel-2 Mission in part overlap and therefore the satellite data can complement each other
- Masking of clouds and clear pixels in both missions provide comparable performance

	CE of clear (valid) pixels	OE of clouds	Total of validated pixels
Sentinel-2 L2A SCL	10,9%	16,5%	> 2.500.000
Sentinel-3 L2 flags	> 19%	8.1%	10.000

https://sentinel.esa.int/documents/247904/3387123/Sentinel-3-MPC-ACR-OLCI-Cyclic-Report-027.pdf

- High spatial resolution of Sentinel-2 SCL can support validation activities of other satellites and L2 products with lower spatial resolution, as well as improve users applications
- Sentinel-2 SCL can be used for validation of Sentinel-3 OLCI L2 flags for land, water, and snow.
- Additional potential:
  - sharing of validation references
  - organization of joint ad-hoc campaigns
  - discussion about user requirements / interests, the validation protocol, statistical metrics applied for reporting performance is of high interest.



Thank you for your attention!

Magdalena Main-Knorn, Bringfried Pflug, Jerome Louis, Vincent Debaecker, Uwe Müller-Wilm, Valentina Boccia

magdalena.main-knorn@dlr.de; www.DLR.de/eoc

For more details on Sen2Cor Atmospheric Correction Module:
Poster "Validation of atmospheric correction: Collaboration and exchange between Copernicus Sentinel-2 and Sentintel-3 teams?", B. Pflug, et al.